CONSUMPTIVE USE OF WATER BY CORN, GRAIN SORGHUM, AND FORAGE SORGHUM IN OKLAHOMA, 1954

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PREFACE

The experimental work of this thesis research project was performed under the Agricultural Engineering Department, Oklahoma A & M College, as a part of the irrigation research of the Oklahoma Agricultural Experiment Station. The soil moisture study method was used to determine the transpiration and consumptive use of corn, grain sorghum, and forage sorghum throughout the growing season for central Oklahoma.

The results presented herein will permit more efficient irrigation system design and will be beneficial in improving irrigation management practices for obtaining optimum yields of the crops studied. The transpiration data presented may be used directly in irrigation system design by the application of an irrigation efficiency factor.

This experimental work was conducted on the Oklahoma Livestock Experiment Station, Fort Reno. I am very grateful to Dwight F. Stephens Superintendent of Station, for his personal assistance and for making available the experimental area and the facilities and equipment of the Station.

Appreciation is extended to my thesis adviser, James E. Garton, Assistant Professor Irrigation, for his assistance in planning and conducting the experiment and for his suggestions during the data analysis and writing the report.

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I. INTRODUCTION

The availability of water to crops is one of the primary limiting factors in agricultural production. The science of irrigation has been developed to supply and control this very variable factor. Many areas in this country depend solely on irrigation for agricultural production; other areas need irrigation to supplement rainfall. Several of the irrigated valleys of the West do not have an adequate water supply. Where irrigation water is supplied from ground water, receding water tables are causing alarm and are increasing irrigation costs. In our increasing use of irrigation to meet the growing demand for food, good utilization of our limited water supply is increasing in importance.

In the normal process of growth, plants transpire water into the atmosphere and utilize it in the development of plant tissue. Some water evaporates directly from the soil into the atmosphere. The total utilized in transpiration, in building plant tissue, and that evaporated from the adjacent soil or from rainfall intercepted by plant foliage is called consumptive use.

A knowledge of the consumptive use of water by crops is of primary importance in any irrigated agricultural enterprise. The design of an economical and functional irrigation system to obtain optimum yields depends on the consumptive use of water. The practical problem of when to irrigate also basically depends on the rate of consumptive use. In designing an irrigation system and developing management practices for optimum yields, the pattern of consumptive use over the growing season must be known. Consumptive use varies quite widely with the stage of maturity of the crop, the type of crop grown, and variation in climatic factors during the growing season. For an economical and adequate design, the peak consumptive use, when it occurs during the growing season, and the seasonal consumptive use must be known for each crop.

A knowledge of consumptive use can be very useful in solving the problem of scheduling irrigations. Very frequently a considerable reduction in yield results from failing to irrigate soon enough. The physiological nature of some plants is such that a moisture stress in the plant results in serious damage. The results from the tests on corn in this experiment illustrate the serious reduction in yield that can result from plant moisture stress.

Over irrigation may also damage the plants. Maintaining a high soil moisture level may result in depressed yields. The disadvantage of over irrigation is not usually depressed yields, however, but is a reduction in net returns due to the uneconomical use of water. Where the availability of water is limited and the area that can be irrigated relatively unlimited, a knowledge of the variation of consumptive use with yield will permit the selection of a consumptive use level that will irrigate the optimum acreage for the greatest net return.

Considerable work is being done in many states to determine consumptive use by the use of climatic factors in an empirical relationship. Since soil moisture studies, as used in this experiment, are the most accurate method of determining consumptive use, they are valuable for developing and improving the accuracy of the empirical method.

To insure that water stored in the soil is readily available to the plants, the depth of the soil from which the crop withdraws most of its water must be known for each crop. Previous work has indicated that moisture is not extracted uniformly throughout the plant root zone. When the available soil moisture is extracted from part of the root zone profile, the plants will not be able to extract sufficient moisture from the remaining portion to maintain optimum growth during periods of maximum usage. A moisture stress develops which permits the plants to live for some time but severely retards their growth. Soil moisture extraction patterns are desirable, therefore, for determining the consumptive use for optimum yields.

II. OBJECTIVES

The objectives of this research project were as follows:

1. Determine the transpiration and consumptive use of water by corn, grain sorghum, and forage sorghum for optimum yields in central Oklahoma, 1954, by the soil moisture study method.
    a. Determine the seasonal transpiration pattern.
    b. Determine the peak average daily transpiration between irrigations.
    c. Determine the peak monthly transpiration.
    d. Determine the seasonal transpiration.
    e. Determine the seasonal consumptive use.
2. Determine the effect of doubling the recommended rate of nitrogen application on the yield of each crop.
3. Determine the soil moisture extraction pattern for each crop.

III. LITERATURE CITED

Definition of Terms

The terms used in this report were defined by Young[22] as follows:

Irrigation Requirement: The quantity of water, exclusive of precipitation, that is required for crop production. It includes surface evaporation and other economically unavoidable wastes. Usually expressed in depth for any given time (volume per unit area for given time).

Water Requirement: The quantity of water, regardless of its source, required by a crop in a given period of time, for its normal growth under field conditions. It includes surface evaporation and other economically unavoidable wastes. Usually expressed as depth (vloume per unit area) for a given time.

Consumptive Use (evapo-transpiration): The sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil or intercepted precipitation on the area in any specified time, divided by the given area. The consumptive use may be expressed in acre-inches per acre or depth in inches, or acre-feet per acre or depth in feet.

Transpiration: The quantity of water absorbed by the crop that is transpired and used directly in the building of plant tissue in a specified time. It does not include soil evaporation. It is expressed as acre-feet or acre-inches per acre or as depth in feet or inches.

Field Capacity: The moisture percentage, on a dry weight basis, or a soil after rapid drainage has taken place following an application of water. This moisture percentage is reached approximately two days after irrigation.

Permanent Wilting Point: The moisture content of the soil at which the plants wilt and do not recover unless water is added. It is expressed as percentage of moisture based on the oven-dry weight of the soil.

Available Moisture: The quantity of water in the soil that is available for plant use, as limited by the field capacity and the permament wilting percentage. It is expressed as percentage of the dry weight of the soil or as depth of water in inches per foot depth of soil.

Moisture Percentage: The percentage of moisture in the soil based on the weight of the oven-dry material.

Apparent Specific Gravity (volume weight): The ratio of the weight of a unit volume of oven-dry soil of undisturbed structure to that of an equal volume of water, under standard conditions.

Real Specific Gravity: The ratio of the weight of a single soil particle to the weight of a volume of water equal in volume to the particle of soil.

Soil Moisture: The water in unsaturated soil. It is expressed as a percentage on a dry weight basis, or in inches per foot depth of soil.

Factors Affecting Consumptive Use

Many factors operate singly or in combination to influence the amount of water consumed by plants. These factors are not necessarily constant but may fluctuate from year to year as well as from place to place. The rate of consumptive use of water primarily depends upon the climate, soil moisture supply, vegetation, and irrigation practices. A summary of these conditions affecting consumptive use, reported by Israelsen[14] are as follows:

The factors included in climate that particularly affect consumptive use are precipitation, temperature, humidity, wind movement, and length of growing season. The relative humidity decreases with an increase in temperature, increasing the rate of evaporation and transpiration. Very low temperatures may retard plant development and very high temperatures may cause dormancy. Hot, dry winds frequently cause periods of high consumptive use in the Southwest.

Transpiration depends upon the available soil moisture supply. If the transpiration from the leaves exceed the rate of absorption by the roots, wilting occurs and the plant growth is impeded. In clay soils the available soil moisture may not move through the soil fast enough to supply the optimum plant needs. The other extreme can exist when excessive transpiration may not convey sufficient plant food into the plant for normal metabolism to most efficiently utilize the moisture. Evaporation from the soil surface may be high if the surface is wet or if capillary water is moving to the surface from a high ground water table.

Vegetative factors affecting consumptive use include the type of vegetation, the nature and density of its foliage, and the stage of development of the plants. As the leaf area of plants enlarges, the consumptive use increases and reaches a maximum as the plants approach maturity. The consumptive use drops rapidly as maturity proceeds and the function of the plant is transferred from growth to processes of ripening and reproductive development.

Irrigation factors that influence consumptive use are the field irrigation layout, preparation of the field for application, conveyance of water, and the method of water application. Plant diseases and pests may reduce consumptive use by inhibiting plant growth. Noxious weeds may affect consumptive use by increasing the foliage density or by reducing the area irrigated if crops cannot be grown on infested areas.

Methods of Determining Consumptive Use

Israelsen[14] lists the principal methods of determining the amount of water consumed by agricultural crops and natural vegetation as follows: tank and lysimeter experiments, field experimental plots, soil moisture studies, analysis of climatological data, integration method, and inflow-outflow for large areas. Most of the work that has been done in determining consumptive use has been with field experimental plots.

A common method used to determine the consumptive use of water is to grow the plants in lysimeters or tanks and measure the quantity of water necessary to maintain satisfactory growth. The tanks are commonly 2 to 3 feet in diameter and 6 feet deep. The reliability of results depends on how nearly natural conditions are reproduced. Artificial conditions are caused by the limitations of soil, size of tank, regulation of water supply, and sometimes environment.

Field experimental plots have been used extensively in determining the water requirements of crops. They are usually more dependable than measurements with tanks or lysimeters because they represent natural conditions and are considerably larger in area. The usual procedure was to measure the water applied to the plots at each irrigation and to measure any appreciable runoff. Frequently, the plots were surrounded by borders to prevent runoff. Applications were usually small enough to prevent appreciable deep percolation. The data that were obtained from field experimental plots were seasonal water requirements. Accurate peak consumptive uses during the growing season could not be obtained by this method.

Some intensive soil moisture studies have been used to determine the consumptive use for various crops. This method is suitable for plots or areas where the soil is uniform and the water table will not influence the root zone. This method consists of taking representative soil samples by means of a standard soil tube before and after each irrigation with some samples between irrigations. Samples are usually taken in one foot sections of the major root zone from which the rate of soil moisture depletion is determined.

The method of determining consumptive use by the analysis of climatological data is an empirical relationship adapted to irrigation by Blaney and Criddle[21]. It is expressed as $U = KF$ where U is the consumptive use of the crop in inches for a given time period, K is an empirical coefficient, and F is the sum of the monthly consumptive use factors for the period, (sum of the products of mean monthly temperature and monthly percent of annual daytime hours). This method has come into extensive use recently in many states. Measured consumptive use studies permit a more accurate determination of the empirical coefficient K. From the measured consumptive use determinations in one area, the consumptive use in another area may be estimated by this method.

The integration and the inflow-outflow methods have been used to determine the consumptive use of large irrigated valleys. The intergration method determines a weighted consumptive use from the consumptive uses of the component areas of the valley. Consumptive use by the inflow-outflow method is equal to the water that flows into the valley during a 12 month period, plus the yearly precipitation on the valley floor, plus the water in ground storage at the beginning of the year, minus the water in ground storage at the end of the year, minus the yearly outflow.

Consumptive Use of Water by Corn

The first work reported on the water requirements of corn was by Bloodgood and Curry[5] of experiments in the Mesilla Valley, New Mexico. They found that in tests on seven fields, the water requirement for maximum yields was 30 inches. The growing season was reported as 120 days which would result in an average daily requirement of 0.25 inches of water for the growing season.

Hemphill[13] in a study of the irrigation requirements of corn in South Texas reported that the water requirements for optimum yield were in the range of 15 to 20 inches. A similar requirement of 17 inches was reported by Fortier[7] for corn grown at Hays, Kansas in 1904.

The first extensive experimentation to determine the water requirements of corn was done by Beckett and Huberty[2] at Davis, California. Indian corn for silage was tested under four to seven water treatments between 1910 and 1922. A summary of their results is given in Table 1. All the water requirements for the Indian corn at Davis, California, were determined on non-replicated plots with the exception of the 1922 experiment which was in three replicates.

Table 1. Water requirements for Indian corn grown at Davis, California, 1910-22.

Year	Water Requirements for Maximum Yield Inches
1910	19.9
1911	30.3
1912	24.1
1913	23.7
1914	40.7
1915	32.0
1922	27.9

Brown[6] reported the water requirements of corn on peat lands in the Sacramento-San Joaquin Delta. Both field plots and evapo-transpiration tank studies were used. The water requirement for the field plots was determined to be 28.4 inches. The consumptive use determined from the tank studies was 43.8 inches.

Stafford[21] reported that the maximum monthly water requirement for corn in the Sacramento-San Joaquin Water Supervision area was 10.2 inches. The average daily requirement for the peak month was 0.34 inches per day. The total seasonal use was reported to be 29.2 inches.

Pittman and Stewart[18] reported on twenty-eight years of irrigation experimentation near Logan Utah, 1902-29. Several years of corn experimentation resulted in optimum yields from the application of 20 to 30 inches of water. The yields were somewhat depressed by the application of more than 30 inches.

Fortier and Young[8] reported the water requirements of corn for five years of experimentation at Mercedes, Texas. A summary from 42 tests indicated the range for optimum water requirements to be from 17.2 to 23.9 inches.

Extensive evapo-transpiration tank tests were performed on corn by Fortier and Young[9] at Davis, California, 1927-28. The results from 21 tests indicated that the average water requirement was 40.6 inches. This requirement was more than corn used under field conditions in other areas. The water requirement for corn silage for the same location was 23 inches.

Singleton[20] reported that at Prosser, Washington, the average irrigation water requirement for corn, including farm transportation, runoff, and deep percolation losses, was slightly less than 30 inches. The average rainfall during the growing season was not reported.

Scofield and Orlando[19] reported the water input requirement for corn at the United States Scotts Bluff Field Station in Nebraska, 1941-44. The water input for each year, along with the average daily requirement over the growing season, is presented in Table 2. One water treatment, selected to maintain an adaquate soil moisture level, was used in two to six replicates.

Table 2. Average daily water requirement for corn, United States Scotts Bluff Field Station, Nebraska, 1941-44.

Year	Growing Season Days	Water Input* Inches	Average Daily Requirement Inches
1941	136	20.3	0.15
1942	128	26.4	0.21
1943	156	14.8	0.10
1944	149	17.8	0.12

* Water input was defined as the water application minus runoff plus rainfall.

Barrett and Milligan[1] reported the seasonal transpiration and consumptive use of corn by the soil moisture depletion method for the Ashley and Ferron Valleys, Utah, 1948-50. The results, including the average daily transpiration, is reported in Table 3. The average daily transpiration of corn grown in the Ashley Valley for the three year period was 0.136 inches. This transpiration rate compares with 0.145 inches for corn grown in the Ferron Valley over a two year period.

Table 3. Transpiration and consumptive use, determined by the soil moisture depletion method, Colorado river investigations, Utah, 1948-50.

Year	Growing Season Days	Seasonal Transpiration Inches	Seasonal Consumptive Use* Inches	Average Daily Transpiration Inches
		Ashley Valley		
1948	102	17.2	20.4	.169
1949	135	19.7	23.0	.146
1950	138	12.8	14.6	.093
		Ferron Valley		
1949	120	18.0	21.3	.150
1950	129	18.1	20.6	.140

* Evaporation from each storm was considered to be .30 inch for row crops; for each irrigation, .25 inch.

Land and Carreker[15] reported the results of soil moisture depletion studies on corn at the Agricultural Experiment Station, University of Georgia, between June 10 and August 26, 1952. The maximum daily evapotranspiration rate was 0.28 inches; the minimum, 0.15 inches. The average rate of moisture depletion over the period studied was 0.22 inches per day.

Harrold[11] reported on the daily consumptive use of corn by the use of lysimeters, of the weighing monolith type, over the peak months of July and August, 1953, at the Coshocton, Ohio, Research Station, Soil Conservation Service. The maximum daily consumptive use was 0.38 inches; the minimum, 0.20 inches. The average consumptive use for the two month period was approximately 0.25 inches per day.

Young [22] reported on work done by Blote in the Sacramento-San Joaquin Delta, 1942, in determining the monthly and seasonal consumptive use of water by corn. The peak monthly consumptive use was 10.2 inches for July, an average consumptive use of 0.33 inches per day for the month. The seasonal consumptive use was 29.2 inches.

The consumptive use of water by corn, calculated by the empirical method from climatological data by Garton and Criddle[10], was 23.0 inches for Fort Reno, Oklahoma. The net irrigation requirement was calculated to be 9.2 inches.

Consumptive Use of Water by Grain Sorghum

Marr[16] reported the water requirement for Dwarf Milo grain sorghum in the Salt River Valley of Arizona was 27.3 inches for maximum yield. The average water requirement for 21 fields tested was 25.5 inches.

Bechett and Huberty[1] reported the seasonal water requirements for Dwarf Milo for a four year period in the Sacramento and San Joaquin Valleys of California. A summary of their results is given in Table 4.

Table 4. Water requirements for dwarf milo in the Sacramento and San Joaquin Valleys of California, 1910-22.

Year	Water Requirements for Maximum Yield Inches
1910	17.4
1911	28.8
1913	26.7
1922	30.2

Fortier[7] reported the water requirements of the arid and semiarid lands of the Missouri and Arkansas River Basins. The water requirement of Kafir corn was 21 inches near Lawton, Oklahoma, in 1919. The water requirement was determined to be 18 inches at Hays, Kansas, 1904. This water requirement corresponded closely to the 17 inches determined from similar tests near Garden City, Kansas. The requirement for Garden City increased to 30 inches in 1916. The water requirement for Sumac sorghum at the same location in 1916 was also determined to be 30 inches.

Fortier and Young[8] reported the seasonal water requirements of the arid and semi-arid lands of the Southwest. A summary of 16 tests on Kafir corn determined a range in the water requirements from 15.8 to 18.5 inches for maximum yield. In 35 tests with Milo grain sorghum, the optimum water requirements varied from 11.5 to 20.0 inches.

The most comprehensive experimentation to determine the water requirements of grain sorghum was performed by McDowell[17] over a five year period in the Wichita Valley of Texas. Eight water treatments were used on replicated field plots, 1/22 acre in size. The optimum range of water requirements for the years 1932 to 1936 inclusive are presented in Table 5. The grain sorghum became dormant in 1936 because of extremely clear, hot, dry weather accompanied by low humidity, excessive evaporation, and an occasional hot wind. The variety tested, Hegari, did not respond favorably under these abnormal climatic and seasonal influences. The optimum water requirement for conditions prevailing in the Wichita Valley was reported to be 38 to 39 inches.

The consumptive use of water by grain sorghum, calculated by the empirical method from climatological data by Garton and Criddle[10], was 23.0 inches for Fort Reno, Oklahoma. The net irrigation requirement was calculated to be 9.2 inches.

Table 5. Water requirements for grain sorghum in the Wichita Valley of Texas, 1932-36.

Year	Water Requirements for Optimum Yield Inches
1932	23.6 to 32.6
1933	27.6 to 33.6
1934	30.8
1935	33.3 to 37.3
1936	51.8

Consumptive Use of Water by Forage Sorghum

The only data located on the water requirement of forage sorghum were reported by Fortier and Young[8] on sorghum hay grown at the New Mexico Experiment Station. In 1915, the seasonal water requirement was 35 inches for sorghum hay grown on fine sandy loam soil. Irrigation water was applied for the months of April through August. The peak monthly application was 11.5 inches in August, a daily rate of 0.37 inches. The minimum application was 6.1 inches in July, a daily rate of 0.20 inches.

III. PROCEDURE

Location of Experimental Area

The Fort Reno Livestock Experiment Station, Oklahoma, was selected for the location of the experimental plots. The plots were located on Canadian fine sandy loam soil, underlain by a clay subsoil which varied in depth from $2\frac{1}{2}$ feet under the corn plots to $3\frac{1}{2}$ feet under the forage sorghum plots. Uniform plots were selected from each of the three crops, corn, grain sorghum, and forage sorghum, grown on a newly irrigated, 30 acre field.

Equipment Used

Irrigation water was pumped from a well, piped to the plot area in sprinkler main line pipe, and applied to the furrows by the use of gated pipe. An orifice plate flow meter and recorder were used to measure and record the rate of flow. A gate valve on the pump discharge was used to regulate the flow. The electric motor and pump unit, orifice plate flow meter and recorder, and gate valve are illustrated in Figure 1. An official rain gage was used to measure the rainfall. Moisture samples were taken by the use of a standard soil sampling tube and a post-hole auger sampler. Apparent specific gravity samples were taken with a Pomona soil sampler. Moisture samples were dried in an electric oven.

Figure 1. Electric motor and pump unit, orifice plate flow meter and recorder, and flow regulating gate valve.

Plot Layout and Treatments Used

The plots were laid out in a randomized block, split-plot statistical design to permit statistical analysis of the yield. Six row main plots and 3 row sub-plots, 100 feet long, were selected for the corn. Eight row main plots and 4 row sub-plots, 100 feet long, were selected for the grain and forage sorghum. This size of sorghum plots was selected because of its adaptability to the stand. Variability in stand between rows resulted from poor adjustment of the 4 row planter. One outside planter gave a good uniform stand. The selection of 8 row plots permitted two uniform rows of good stand to be in the center of each main plot for yield sampling.

Four water treatments were used on each crop to determine the optimum consumptive use. The treatments were as follows:

T_1 = No irrigation water applied

T_2 = Apply water after plants wilt one week

T_3 = Apply water at the beginning of the wilting stage

T_4 = Maintain soil moisture above 25 percent of available moisture.

The water treatments were the main plot treatments. Three replicates were selected and blocked in the layout. Treatments were randomized within each block.

Two levels of nitrogen were selected as the sub-plot fertility treatments. The two treatments were as follows:

F_1 Single side dressing of nitrogen

Corn: 50#/Acre, 10# at planting plus 40# side dressing,

Grain and Forage Sorghum: 25#/Acre

F_2 Double side dressing of nitrogen

Corn: 90#/Acre, 10# at planting plus 80# side dressing,

Grain and Forage Sorghum: 50#/Acre.

The nitrogen rates were recommended from a soil analysis of the field by the Soils Department, A & M College. The fertility sub-plots were randomized within each main plot.

Crop Management Procedure

The corn was planted the first week in May; the grain and forage sorghum, June 11. The corn variety planted was Lincoln 101 hybred. Ten pound of nitrogen per acre was drilled with the corn at planting. Sugar Drip forage sorghum and Dwarf kafir 44-14 grain sorghum varieties were planted.

The stand of the corn was approximately 11,500 stalks per acre. The average stalk spacing was 15.7 inches. Irrigated corn on productive soil frequently is planted to a stand of 16,000 to 18,000 stalks per acre. The corn was side dressed with ammonium nitrate July 6; the sorghums, July 21. All crops received two cultivations. Some chopping and one spraying were necessary to keep the sorghum plots free of weeds.

Irrigation Procedure

Irrigation water was applied to the plots through gated pipe. Furrow irrigation was used with borders built around each plot. The use of the gated pipe for furrow irrigation is illustrated in Figure 2.

Figure 2. Furrow irrigation with gated pipe.

All the water was held on the plots, except for minor losses that occasionally occured as a result of breakovers. Four inch applications were used on the corn plots; three inch, on the sorghum plots. The application rate was selected as one inch per hour. The infiltration rate was approximately 0.3 inch per hour. This application rate was selected to minimize the time required to remove the irrigation system from field use and to permit the meter recorder to operate in a more accurate reading range. Due to the slope of the plots, uniform water penetration over the entire plot area was not obtained.

When to irrigate was determined by comparing the soil moisture percentage of the top foot of soil depth with the wilting point. The wilting point, determined by soil moisture sampling when the plants were in the wilt stage, was found to range from 7.5 to 8.5%.

Soil Sampling Procedure

The transpiration data for each crop were calculated from consecutive soil moisture samplings. Samples were taken before irrigation, the second day after irrigation at which time the soil had approximately reached field capacity, and the third and fourth day after irrigation. Additional samples were taken between the fourth day and prior to the next application as time permitted.

The center replicate was selected as representative of the plot area for soil moisture sampling. Three sites were selected on each plot. Profile samples were taken with a soil tube sampler at one foot intervals to a depth of three feet at each site. Three feet was selected as the feeder root depth for moisture extraction. Gray[1] lists the feeder root depth for corn and grain sorghum as $2\frac{1}{2}$ feet. Three sites were located along the center two rows of the main plots at approximately 30, 55, and 75 feet from the headwater end. Consecutive samples were taken 6 to 8 inches apart along the row for the sorghums. Since the average corn spacing was 15.7 inches, care was taken in selecting the sample locations approximately the same distance from the stalk along the row each time. The site locations were offset approximately 5 feet from the center of the headwater center, and tailwater third of the plot length in the direction of the tailwater end. This offset was selected to minimize the effect of unequal application due to the slope of the plots. Yield samples were offset the same distance from plot centers.

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[1]Alfred S. Gray. Sprinkler Irrigation Handbook. 4th. Edition. (Glendora, Calfornia, 1952). p. 22.

Standard laboratory procedure was used to determine the moisture content of the soil samples. Each sample was weighed and dried in an electric oven at 105-110° C. for a minimum of eight hours and the dry weights determined. The water content of the samples were expressed as percentage of oven dry weight.

The undisturbed core samples for the apparent specific gravity determinations were taken with a Pomona soil sampler. Three samples were taken at approximately the center of each foot depth of soil sampled for each crop location. The real specific gravity was determined by the use of a 150 ml. pycnometer bottle. A summary of the specific gravity values, along with calculated and estimated values of field capacity and wilting point, are given in Table 22 of the appendix.

Crop Yield Sampling Procedure

Fifty feet of row were sampled for yield from each corn sub-plot on August 25. Samples were shelled and weighed to the nearest $\frac{1}{4}$ ounce on small lever balances. Yields were calculated in bushels per acre. The moisture content of the grain was reasonably low at the time of sampling. In addition to the yield, the stand and ear count were taken.

Twenty five feet of row were sampled for yield from each forage sorghum sub-plot on September 11. The forage samples were weighed on large platform scales to the nearest $\frac{1}{2}$ pound and yields calculated in tons per acre. A representative forage moisture sample was taken from each treatment from which the moisture content, wet weight basis, was determined by oven drying under standard conditions. Yields were adjusted to a standard moisture content of 72%.

The grain sorghum heads were harvested from 25 feet of row from each sub-plot on October 17. The samples were air dried for approximately two weeks to reduce and equalize the moisture content of the grain before threshing. The heads were threshed by a plot thresher from the Agronomy Farm, A & M College. The threshed grain was sieved through screens to eliminate trash. Samples were weighed to the nearest 0.01 pound and yields calculated in bushels per acre.

Procedure for Calculations

The basic formula used in the transpiration calculations is given as follows:

$$d = \frac{P \, A_s \, D}{100}$$

where d = depth of soil moisture depletion in inches,

P = difference in percent of soil moisture between two determinations,

A_s = apparent specific gravity of the soil, and

D = depth of soil sampled in inches.

The average daily transpiration rate between irrigations was determined from each foot of soil for the three foot root zone depth. This transpiration rate was taken as the average rate of soil moisture depletion between the third day after application to prior to the following application. A small amount of evaporation may be included, however it is believed to be negligible. Initial soil moisture samples at the beginning of the growing season for the sorghums and at harvest for all crops were taken to determine the transpiration rate prior to the initial irrigation and between the last irrigation and harvest.

The apparent specific gravities determined for the surface foot were high as a result of a zone of compaction at plow depth and, therefore, were not used. The average values for the second foot were used to represent the first two feet of soil depth for transpiration calculations.

According to studies by Veihmeyer[23] and Hastings[12], the maximum evaporation per storm for row crop irrigation is 0.3 inch. In calculating the transpiration, the effective rainfall over 0.3 inch was added to the transpiration from the surface foot of soil for the period in which it occured. The seasonal transpiration was determined by adding the transpiration for all periods.

The seasonal consumptive use for the grain and forage sorghum was determined by adding the total rainfall during the growing season and the differential soil moisture for the root zone depth between the beginning and the end of the growing season to the total inches of irrigation water applied.

A difficulty arose in determining the seasonal transpiration and consumptive use of corn because no soil moisture samples were taken to cover the period from planting in the first week in May until June 17. The moisture use prior to the first irrigation on July 1 was from soil moisture stored from rainfall in April, May, and June. The total rainfall for this period was 8.63 inches. Eighty percent of this rainfall, 6.91 inches, was assumed available to the crop. Since 3.34 inches inches of transpiration was measured from June 17 to July 1, the remainder of the 6.91 inches, 3.57 inches, was used from May 15 to June 17. The total rainfall for this period, the amount of irrigation in inches, and the differential soil moisture for the root zone depth in inches between initial sampling and harvest were added to determine the consumptive use.

The yields were analyzed statistically for each crop according to the standard analysis procedure. A covariance analysis was run on the corn yields for adjustment of yields to a common stalk basis. Forage yields uncorrected for moisture and corrected yields to 72% moisture were analyzed statistically for the forage sorghum.

V. RESULTS AND ANALYSIS

Yield, Transpiration, and Consumptive Use for Corn

The corn yields in bushels per acre for the water and fertility treatments are summarized in Table 6. The yields were analyzed statistically to determine the significance of difference between the water treatment and the fertility treatment means and their interaction. Since the stand was somewhat variable, a covariance analysis was used to adjust the yield for stand. This analysis is presented in Table 7. The difference in the mean yield for water treatments was highly significant to the .001 probability level. The fertility treatments and the interaction of the water and fertility treatments were not significant. The application of 90 pounds of nitrogen per acre did not significantly increase the yields over the application of 50 pounds per acre.

The confidence limits for the difference between the water treatment means to the .05 probability level are presented in Table 8. These limits indicate that T_4 is the water treatment for optimum yield. Since the limits for the difference between T_4 and T_3 do not include zero as a value, T_4 is significantly different from T_3 to the .05 probability level. Table 9 gives the standard error for means, standard error for difference between means, and coefficient of variation for water treatments.

The total corn yields from 50 feet of row sampled are illustrated in Figure 3. A difference can be noted in the quantity of yield and the ear size between water treatments. The appearance of the plots

Table 6. Corn yields in bushels per acre.

Fertility Treatments	Water Treatments					
	T_1	T_2	T_3	T_4	Means	Adjusted Means
F_1	0.0	23.5	48.5	68.0	35.0	35.1
F_2	0.0	27.8	48.6	69.4	36.4	36.3
Means	0.0	25.6	48.6	68.7	35.7	
Adjusted Means	1.9	25.5	48.1	67.4		
Irrigation Water Applied Inches	0.0	8.0	12.0	16.0		

Table 7. Covariance analysis of yield against stand for corn.

Source	df	Variance	F	P
Main plots				
Replications	2			
Water treatments	3	3,412.94	204.74	.001
Main plot error	5	16.67		
Sub-plots				
Fertility treatments	1	8.48	< 1.0	-
Water x Fert. interaction	3	-3.25	< 1.0	-
Sub-plot error	7	12.97		

Table 8. Confidence limits for the difference between water treatment means to the .05 probability level.

Treatment Comparisons	Corn	Grain Sorghum	Forage Sorghum Moisture Uncorrected	Forage Sorghum (Moisture Corrected)
$T_2 - T_1$	21.7 to 24.5	65.2 to 86.8	16.5 to 24.5	14.1 to 21.5
$T_3 - T_1$	44.1 to 48.3	74.2 to 95.8	22.7 to 30.7	20.2 to 27.5
$T_4 - T_1$	65.1 to 69.7	74.8 to 96.4	27.2 to 35.2	27.7 to 35.1
$T_3 - T_2$	21.0 to 24.2	-1.8 to 19.8	2.2 to 10.2	2.4 to 9.8
$T_4 - T_2$	40.1 to 43.7	-1.2 to 20.4	6.7 to 14.7	9.9 to 17.3
$T_4 - T_3$	17.6 to 21.0	-10.2 to 11.4	0.4 to 8.4	2.8 to 10.2

Table 9. Standard error for means, standard error for difference between means, and coefficients of variation for water treatments.

Statistic	Corn	Grain Sorghum	Forage Sorghum Moisture Uncorrected	Forage Sorghum Moisture Corrected
Standard Error Mean	1.64	3.08	1.16	1.07
Standard Error Difference	2.32	4.36	1.64	1.51
Coefficient of Variation	10.2%	12.1%	11.1%	11.5%

Figure 3. Yield of corn from 50 feet of row sampled.
Fort Reno, Oklahoma, 1954.

near maturity is illustrated in Figure 4. The plants in the T_1 plots died before reaching maturity. The plants under T_2 had a light, yellowish color with considerable dead leaf area. Very little difference could be noted between T_3 and T_4 plots with appeared to be vigorous in growth and have a deep green color.

The moisture use - yield curves, which includes a transpiration - yield and a consumptive use - yield curve, are illustrated in Figure 5. The optimum seasonal transpiration was calculated to be 22.29 inches of water; the consumptive use, 26.70 inches. The steep slope of the curve indicates that maximum yields were not obtained by the water treatments used. A delay in obtaining main line pipe and couplers caused the treatments to go through a 10 day wilting stage prior to the first application. This period of moisture stress is believed to be largely responsible for the failure to obtain maximum yields. The large difference in yields between water treatments indicate strongly that moisture stress in corn seriously reduces the yield. For optimum yields, the soil moisture level should be maintained well above the wilting point throughout the growing season.

The average daily transpiration curves for the corn treatments are presented in Figure 6. These curves illustrate the rate of transpiration for each treatment throughout the growing season. The peak for both the average daily and the peak monthly transpiration came in the hot, dry month of July as the plants approached maturity. Table 10 presents a summary of the transpiration and consumptive use. The peak daily rate for one irrigation period was calculated to be .345 inches for optimum yields. This rate occured for the period July 12-20. The average daily rate of use for the irrigation season was .280 inches.

T_4 Left — T_1 Center — T_2 Right

T_1

T_4

T_2

Figure 4. Corn plots near maturity. Fort Reno, Oklahoma, 1954.
(Three foot soil sampling tube illustrates height of corn).

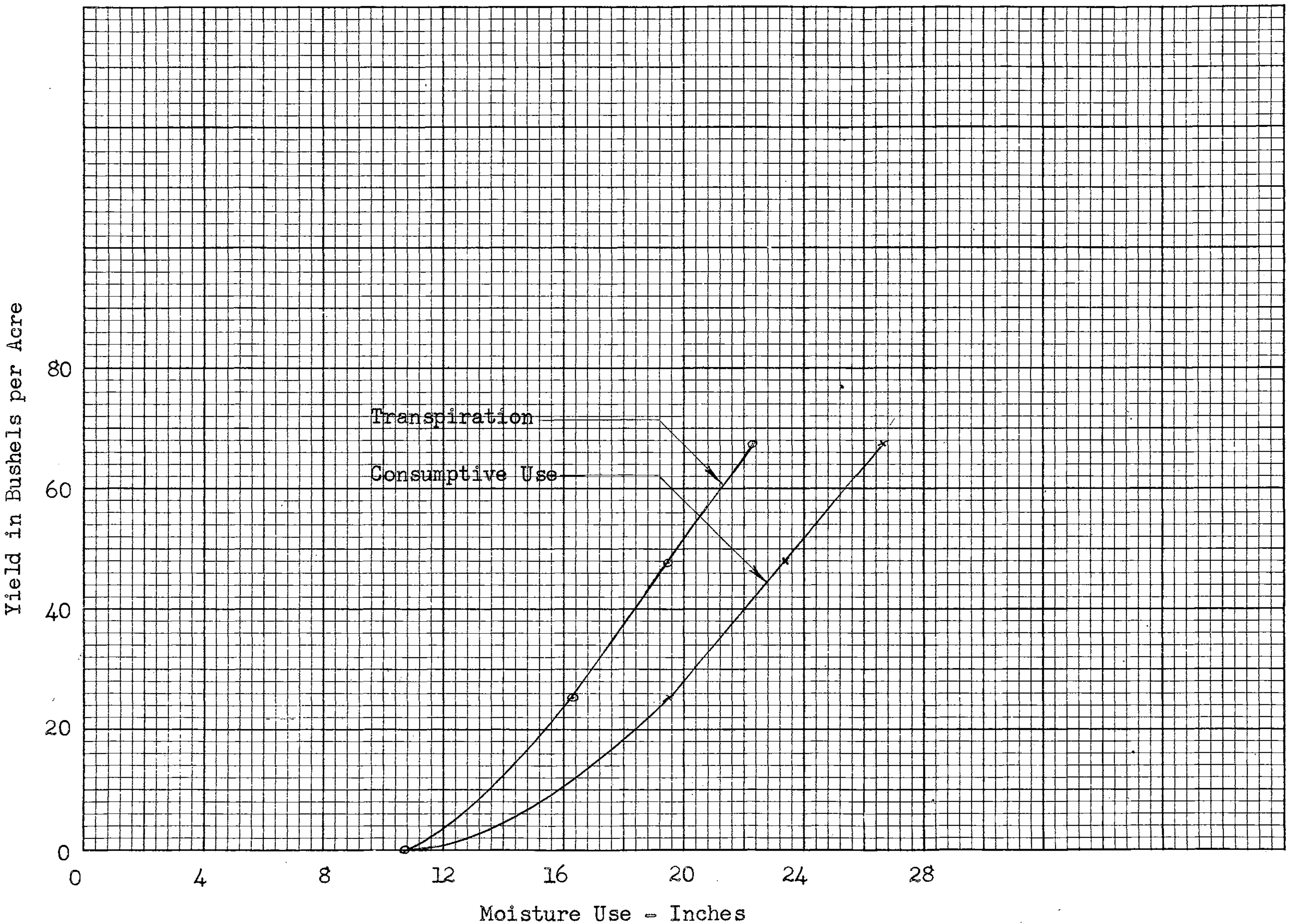

Figure 5. Moisture use - yield curves for corn. Ft. Reno, Oklahoma, 1954.

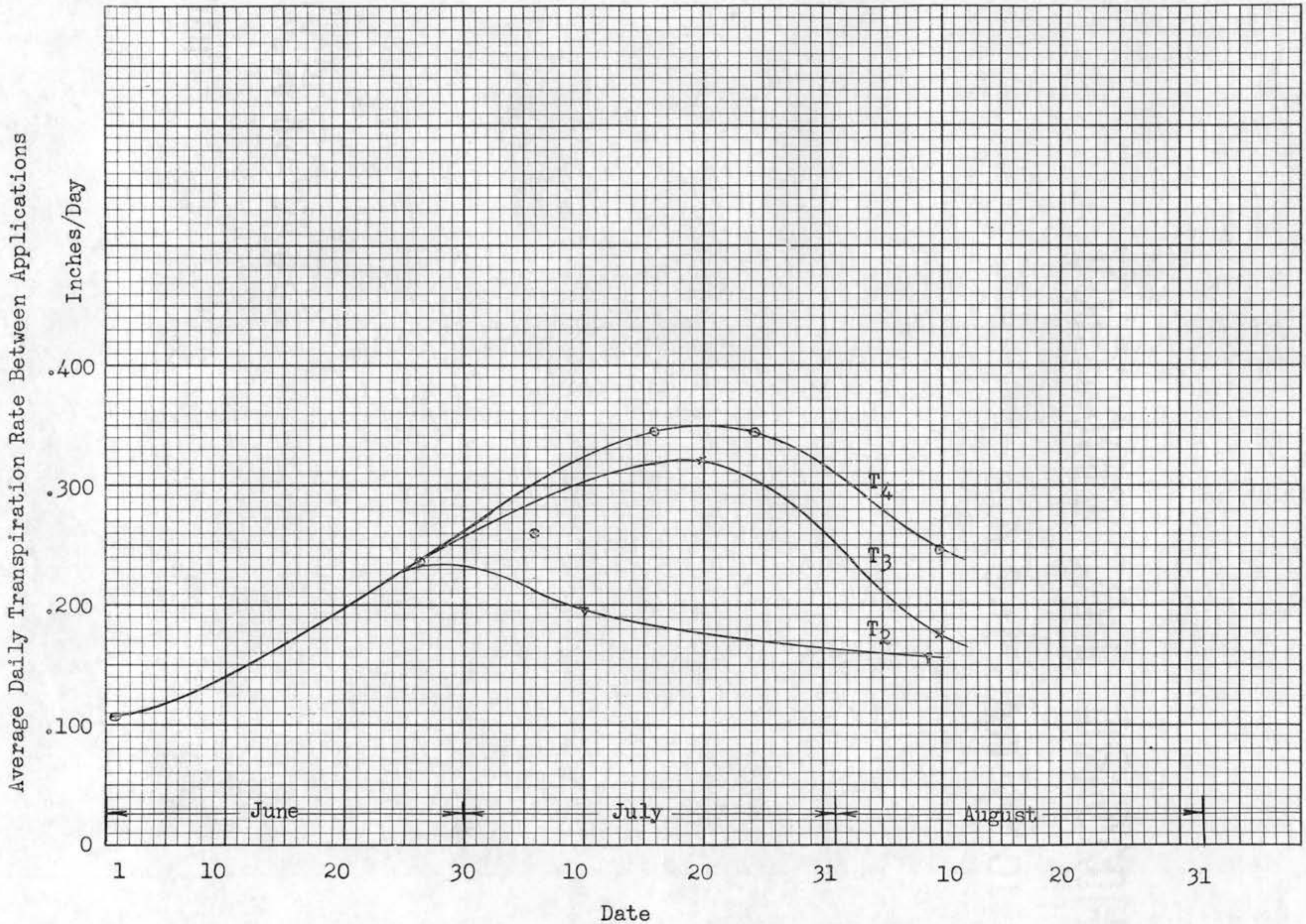

Figure 6. Average daily transpiration curves for corn. Ft. Reno, Oklahoma, 1954.

Table 10. Summary of transpiration and consumptive use of water by corn, grain sorghum, and forage sorghum.

Crop & Treatment		Peak Daily Transpiration* Inches	Date for Peak Transpiration	Average Daily Transpiration for Irrigation Season Inches	Peak Monthly Transpiration** Inches	Seasonal Transpiration Inches	Consumptive Use Inches
Corn	T_4	.345	July 12 - 20	.280	9.22	22.29	26.70
	T_3	.322	July 14 - 26	.228	8.19	19.46	23.38
	T_2	.194	July 1 - 20	.171	5.44	16.32	19.50
Grain Sorghum	T_4	.386	July 30 - Aug 7	.262	9.69	21.80	24.32
	T_3	.290	Aug 20 - Sept 1	.226	8.60	18.35	21.91
	T_2	.188	July 16 - Aug 7	.182	5.66	15.04	16.40
Forage Sorghum	T_4	.381	July 29 - Aug 5	.330	11.61	21.74	23.68
	T_3	.343	July 23 - Aug 5	.211	8.93	17.37	19.29
	T_2	.216	Aug 5 - Aug 24	.169	5.84	12.24	16.05

* Peak daily transpiration is the peak average daily transpiration between irrigations.

** The peak monthly transpiration occured in July for the corn and in August for the grain and forage sorghum.

The peak monthly rate which occured during the month of July was 9.22 inches. The seasonal transpiration was 22.29 inches; the consumptive use, 26.70 inches. The irrigation water applied for this treatment was 16 inches in three 4-inch applications. Irrigation application, transpiration, and consumptive use data are given in detail in Table 19 of the appendix.

The seasonal consumptive use of 26.7 inches calculated for corn is 3.6 inches greater than the 23.0 inches determined by the empirical method from climatological data for El Reno by Garton and Criddle[10]. The net irrigation requirement was 16.0 inches which is 6.8 inches greater that the 9.2 inches calculated by the empirical method. The higher consumptive use than normal can be attributed to the extreme hot, dry growing season.

Consumptive use and water requirement data reviewed in literature for other sections of the country are very variable, both between locations and between years at the same location. Since climatic conditions considerably effect consumptive use, the results of this experiment cannot be accurately compared with results from other locations.

<u>Yield, Transpiration, and Consumptive Use for Grain Sorghum</u>

The grain sorghum yields in bushels per acre for the water and fertility treatments are summarized in Table 11. A statistical analysis of the yield to determine the significance of the difference between the water and fertility treatment means and their interaction is presented in Table 12. The difference in the mean yield for water treatments was highly significant to the .001 probability level. The fertility treatments and the interaction of the water and fertility

Table 11. Grain sorghum yields in bushels per acre.

Fertility Treatments	Water Treatments				
	T_1	T_2	T_3	T_4	Means
F_1	0.89	77.4	86.2	83.7	62.0
F_2	0.96	76.4	85.6	89.3	63.1
Means	0.93	76.9	85.9	86.5	62.6
Irrigation Water Applied Inches	0.0	9.0	15.0	18.0	

Table 12. Analysis of variance of grain sorghum yields.

Source	df	Variance	F	P
Main plots				
Replications	2			
Water treatments	3	10,163.67	178.09	.001
Main plot error	6	57.07		
Sub-plots				
Fertility treatments	1	14.28	< 1.0	-
Water x Fert. interaction	3	10.42	< 1.0	-
Sub-plot error	8	25.61		

treatments were not significant. The application of 50 pounds per acre of nitrogen did not significantly increase the yield over the application of 25 pounds per acre.

The confidence limits for the difference between the water treatment means to the .05 probability level are presented in Table 8. The only significant difference between treatment means was between T_1 and the other three treatments. In comparing the difference between T_2, T_3, and T_4, the limits include zero as a value; therefore, they indicate no significant difference to the .05 probability level. Using a .10 probability level, T_3 was found to be significantly different from T_2, the limits being 0.2 to 17.8 bushels per acre. The standard error for means, standard error for difference between means, and coefficient of variation for water treatments are presented for grain sorghum in Table 9.

The appearance of the grain sorghum treatment plots near maturity is illustrated in Figure 7. Very little difference is noted in the appearance of T_3 and T_4 plots; however, a vast difference in growth and maturity is evident between T_1 and the other treatments. Careful field observation detected a lighter green color in T_2 than in T_3 and T_4. Some lodging also occured in T_2 near harvest which did not occur in T_3 and T_4.

As a result of the statistical analysis and the appearance of the plots, T_3 was selected as the water treatment for optimum yield of grain sorghum. Temporary wilting of the plant for short periods did not significantly reduce the yield. The flattening out of the seasonal, transpiration - yield and consumptive use - yield curves between T_2 and T_4, presented in Figure 8, also illustrates this fact. The physiological

T_4

T_3

T_2

T_1

Figure 7. Grain sorghum plots near maturity.

T_1 foreground contrasted with T_4 in background.

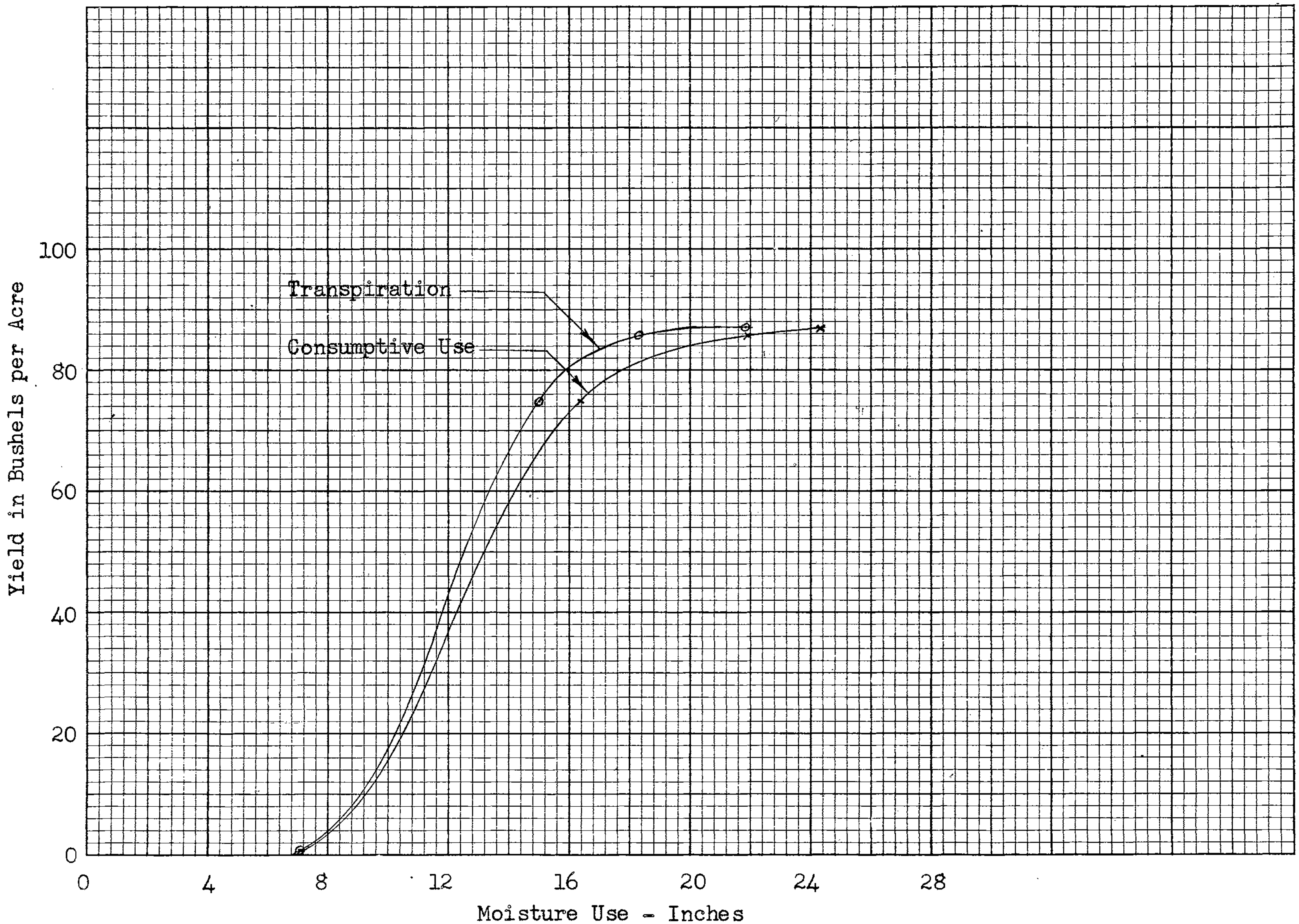

Figure 8. Moisture use - yield curves for grain sorghum. Ft. Reno, Oklahoma, 1954.

make up of the grain sorghum plant permits it to withstand moisture tensions for short periods without incurring serious damage.

Average daily transpiration curves for the grain sorghum treatments are presented in Figure 9. These curves illustrate the rate of transpiration for each treatment throughout the growing season. The peak transpiration occured during August 20 to September 1 for T_3 when the plant was in the heading stage. A summary of transpiration and consumptive use data are presented in Table 10.

The average peak daily transpiration rate between irrigations was calculated to be .290 inches for optimum yields. The average daily rate for the irrigation season was .226 inches. The peak monthly rate, calculated for August, was 8.60 inches. The seasonal transpiration was 18.35 inches; the consumptive use, 21.91 inches. The irrigation water applied for this treatment was 15.0 inches in applications of 3 inches each. Irrigation application, transpiration, and consumptive use data are given in detail in Table 20 of the appendix.

Yield, Transpiration, and Consumptive Use of Forage Sorghum

The forage sorghum yields in tons per acre are presented both for the uncorrected moisture of the forage at harvest in Table 13, and for the moisture corrected to 72% in Table 15 (28% dry matter content, dry weight basis).[1] Since only one forage moisture sample for each treatment was taken to correct for yields, the yields are presented both uncorrected and corrected to standard moisture content.

A statistical analysis of the uncorrected yields to determine the

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[1]Frank B. Morrison, Feeds and Feeding, 21st. Edition, (Ithacha, New York, 1950), p. 318.

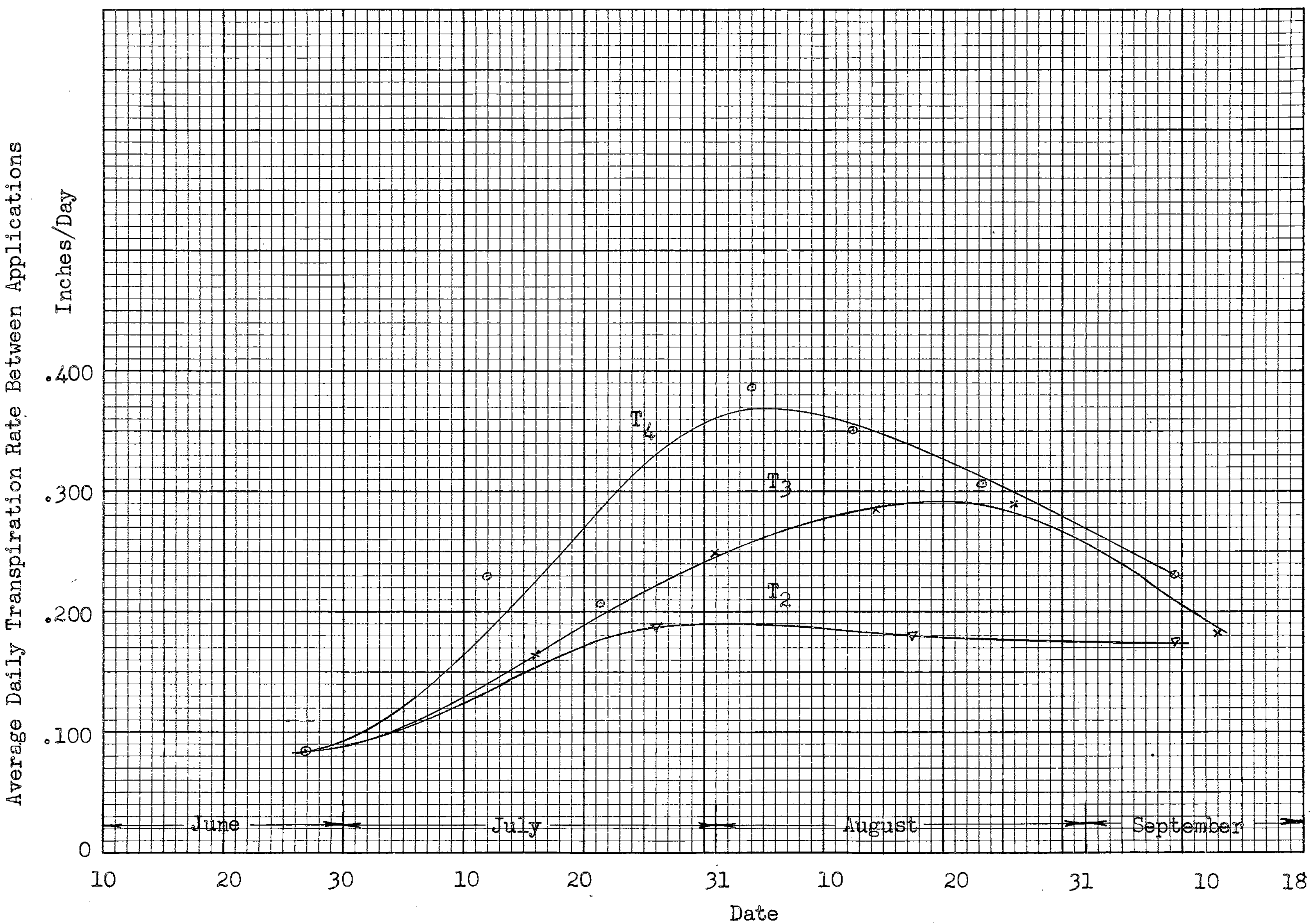

Figure 9. Average daily transpiration curves for grain sorghum. Ft. Reno, Oklahoma, 1954.

Table 13. Forage sorghum yields in tons per acre, moisture content uncorrected.

Fertility Treatments	Water Treatments				
	T_1	T_2	T_3	T_4	Means
F_1	4.63	20.8	30.4	34.5	22.6
F_2	4.05	22.1	31.7	36.6	23.6
Means	4.34	24.8	31.0	35.5	23.1
Irrigation Water Applied Inches	0.0	9.0	15.0	21.0	

Table 14. Analysis of variance of forage sorghum yields, moisture content uncorrected.

Source	df	Variance	F	P
Main plots				
Replications	2			
Water treatments	3	1,139.90	140.90	.001
Main plot error	6	8.09		
Sub-plots				
Fertility treatments	1	6.60	2.01	-
Water x Fert. interaction	3	1.95	< 1.0	-
Sub-plot error	8	3.28		

Table 15. Forage sorghum yields in tons per acre, corrected to 72% moisture content.

Fertility Treatment	Water Treatments				
	T_1	T_2	T_3	T_4	Means
F_1	4.65	21.6	27.1	33.6	21.8
F_2	4.09	22.8	29.5	38.0	23.6
Means	4.37	22.2	28.3	35.8	22.7
Irrigation Water Applied Inches	0.0	9.0	15.0	21.0	

Table 16. Analysis of variance of forage sorghum yields, corrected to 72% moisture content.

Source	df	Variance	F	P
Main plots				
Replications	2			
Water treatments	3	3,242.45	158.47	.001
Main plot error	6	6.82		
Sub-plots				
Fertility treatments	1	20.54	15.80	.01
Water x Fert. interaction	3	9.28	7.22	.05
Sub-plot error	8	1.30		

significance of the difference between the water and fertility treatments and their interaction is presented in Table 14. The differences in the mean yield for water treatments were highly significant to the .001 probability level. The fertility treatments and the interaction were not significant.

For the corrected yields, the statistical analysis is presented in Table 16. The differences in the mean yield for water treatments were also highly significant to the .001 probability level. The means of the fertility treatments were significantly different to the .01 probability level, indicating that the effect of 50 pounds per acre of nitrogen over 25 pounds increased the yield 2.8 tons per acre from 21.8 tons to 24.6 tons. The interaction, which is significant to the .05 probability level, is a result of F_1 being higher than F_2 for T_1 which has no practical significance. The confidence limits, which are presented in Table 8 for the .05 probability level, indicate that T_4 is the optimum water treatment. Table 9 gives the standard error for means, standard error for difference between means, and coefficient of variation for water treatments.

The moisture use - yield curves, which include a transpiration - yield and a consumptive use - yield curve, are illustrated in Figure 10. The soil moisture level of T_4 was maintained at approximately 40% of available moisture above wilting point. The slope of the curves indicate that maximum yields were not obtained with this water treatment. The consumptive use curve for yields corrected to 72% moisture content presents practically a straight line relationship with forage yields.

The average daily transpiration curves for the forage sorghum treatments are presented in Figure 11. These curves illustrate the

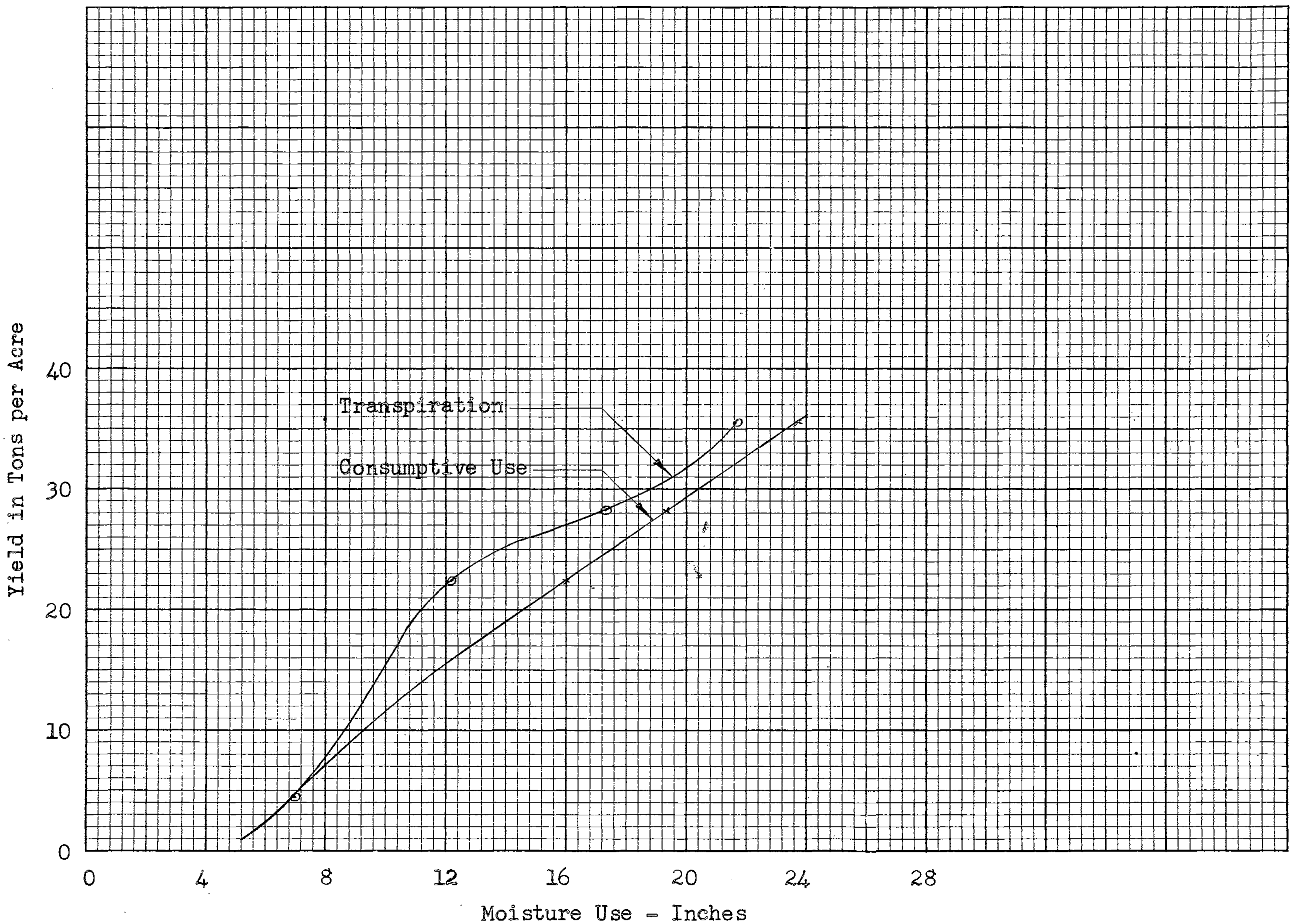

Figure 10. Moisture use - yield curves for forage sorghum. Ft. Reno, Oklahoma, 1954.
(Yields corrected to 72% moisture content).

rate of transpiration for each treatment throughout the growing season. The T_4 reached a maximum rate early in August and maintained a high rate of usage throughout the reaminder of the growing season. T_3 obtained its maximum rate during the latter part of July and early August, the period in which the only effective summer rainfall occured.

The peak daily transpiration rate between applications was calculated to be .381 inches for optimum yields which occured July 29 - August 5. The average daily rate for the irrigation season was .330 inches. The peak monthly rate, calculated for August, was 11.61 inches. Total seasonal transpiration was 21.74 inches; the consumptive use, 23.68 inches. Twenty-one inches of irrigation water were applied to this treatment in applications of 3 inches each. Irrigation application, transpiration, and consumptive use data are given in detain in Table 21 of the appendix.

The appearance of the T_4 plots near maturity is illustrated in Figure 12. The 3 foot soil sampling tube in front of the plots illustrate the height of the sorghum which is approximately 10 feet. Both T_4 and T_3 reached maturity and were similar in appearance. T_1 plots near the maturity date, illustrated in Figure 13, were a marked contrast with their yellowish color, severe wilting, and 2 to 3 feet height. The moisture stress in T_2 prevented it from heading fully at the time of harvest.

The seasonal consumptive use for forage sorghum compares favorably with that for grain sorghum. The average daily and peak monthly transpiration are considerably higher, however, because of the shorter growing season for forage sorghum. No consumptive use data were located from which an accurate comparison of the results of this experiment could be made.

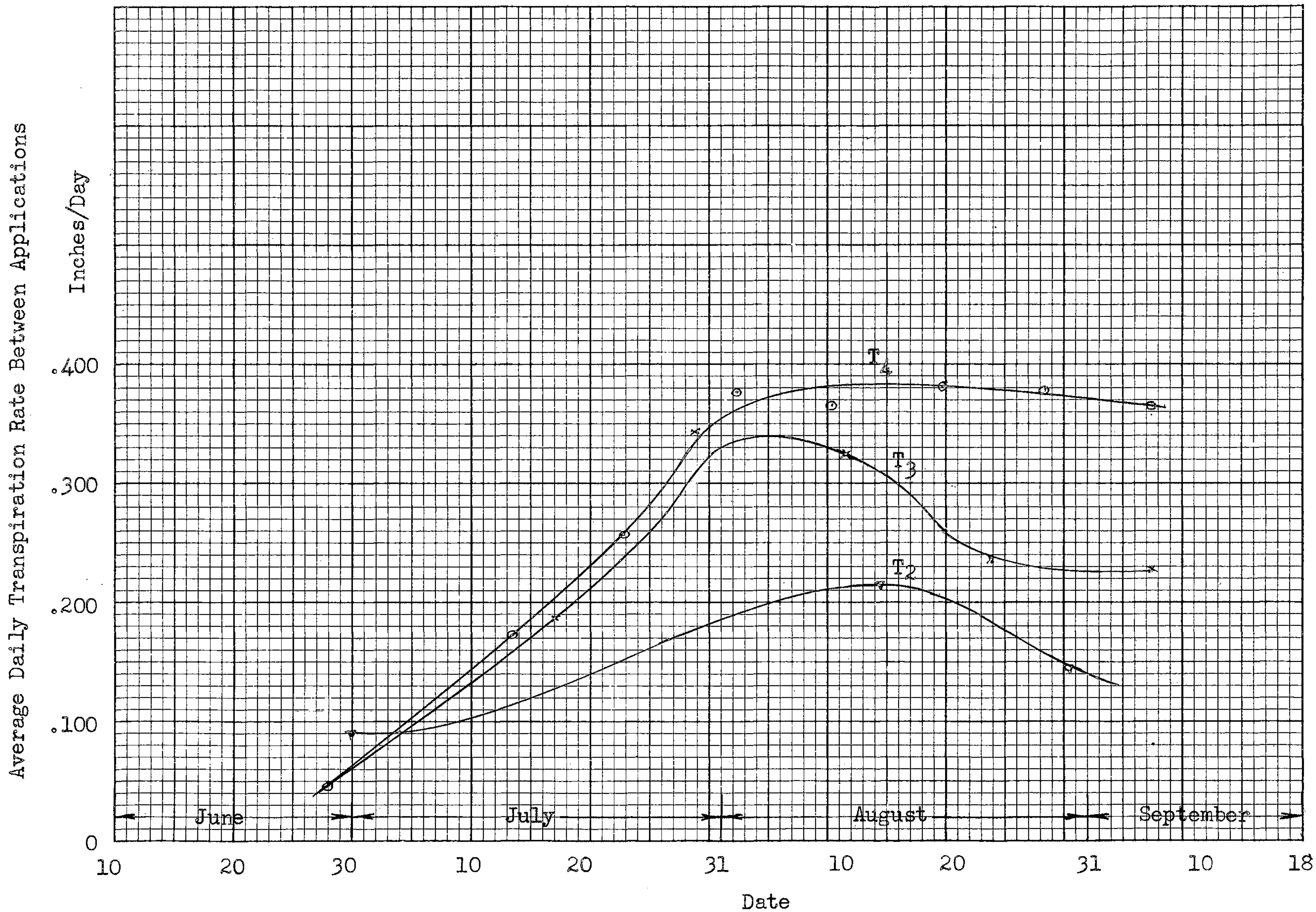

Figure 11. Average daily transpiration curves for forage sorghum. Ft. Reno, Oklahoma, 1954.

Figure 12. Forage sorghum T_4 plots near maturity. (Three foot sampling tube illustrates height).

Figure 13. Forage sorghum T_1 plots near maturity date, bordered on the left by T_3 and on the right by T_2 plots.

Soil Moisture Extraction Patterns

The percent of total soil moisture depletion by each crop at one foot intervals of the root zone depth is presented in Table 17. The results for the optimum water treatments are presented as follows: Corn extracted 45.5 percent of its moisture from the first foot of soil depth, 34.2 percent from the second foot, and 20.3 percent from the third foot. Grain sorghum extracted 59.0 percent of its moisture from the first foot of soil, 32.0 percent from the second foot, and 9.0 percent from the third foot. Forage sorghum extracted 56.9 percent of its moisture from the first foot of soil, 30.6 percent from the second foot, and 12.5 percent from the third foot.

In a recent report on the analysis of soil moisture extraction data, covering many of the irrigated areas of the western states, Shockley stated the following:

> From an evaluation of all the available moisture-extraction data, the conclusion was reached that practically all irrigated crops had a common moisture-extraction pattern even though the soil varied widely in texture and depth. The pattern which developed indicated that, of the total moisture extracted from the soil by the crops, about 40 percent came from the upper quarter of the root zone, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent from the bottom quarter (Fig. 1). Individual crop values in general were within 10 percent of these figures.[1]

Using Fig.1, "Basic moisture extraction pattern", referred to by Shockley, 51 percent of the total moisture extracted from the soil by the crop came from the upper third of the root zone, 34 percent from the middle third, and 15 percent from the bottom third. The results of this experiment compare favorably to those presented by Shockley.

[1]Dale R. Shockley, "Capacity of Soil to Hold Moisture:" *Agricultural Engineering*, Volume XXXVI (February, 1955), p.110.

Table 17. Relation of soil moisture usage to depth for each crop at one foot intervals of the root zone depth.

		Soil Depth in feet		
Crop	Treatment	0-1' %	1-2' %	2-3' %
Corn	T_4	45.5	34.2	20.3
	T_3	52.6	35.3	12.1
	T_2	36.8	39.7	23.5
Grain Sorghum	T_4	54.9	37.5	7.6
	T_3	59.0	32.0	9.0
	T_2	43.0	39.3	17.7
Forage Sorghum	T_4	56.9	30.6	12.5
	T_3	55.0	31.7	13.3
	T_2	64.2	28.9	6.9

Considerable variation in the extraction pattern existed between the different treatments for the same crop. One cause of this variation was the different depths of penetration which resulted from different soil moisture contents between treatments when water was applied.

These data indicate that one-half or more of the moisture is extracted from the top foot of soil. This top foot, therefore, becomes critical in scheduling irrigations. Readily available moisture should be maintained in this soil profile for optimum yields. In addition to the high percentage of moisture obtained from the top foot, a very high percentage of the soil fertility for crop production is also obtained from this same root zone.

Soil Moisture Evaporation

A comparison of daily transpiration and consumptive use following irrigation is presented for T_4 in Table 18. The difference in the average daily consumptive use between the second and fourth days after irrigation and the average daily transpiration between irrigations is an estimate of the soil moisture evaporation. The estimate of daily soil moisture evaporation following irrigation for corn was .247 inches; grain sorghum, .103 inches; and forage sorghum, .082 inches. Daily evaporation from standard pans are listed for Lake Overholser in Table 26 in the appendix. The mean monthly evaporation from standard pans varied from .20 inches per day in May to .39 inches per day in July.

The variation in forage density very likely caused much of the variation in evaporation between the corn, forage sorghum, and grain sorghum. The forage density for T_4 is illustrated for corn in Figure 4, grain sorghum in Figure 7, and forage sorghum in Figure 12.

Table 18. Comparison of daily transpiration and consumptive use following irrigation. (Consumptive use minus transpiration is estimate of soil moisture evaporation following irrigation for T_4).

Crop	Application Date	Average Transpiration Between Applications Inches/Day	Consumptive Use Between 2-4 Days After Application Inches/Day
Corn	July 1	.260	.508
	July 12	.345	.498
	July 20	.344	.647
	July 29	.247	.530
Means		.299	.546
Grain Sorghum	July 8	.230	.258
	July 16	.208	.370
	July 30	.386	.514
	Aug. 7	.350	.488
	Aug. 18	.306	.434
	Aug. 27	.230	.388
Means		.285	.388
Forage Sorghum	July 10	.173	.336
	July 17	.258	.386
	July 29	.379	.403
	Aug. 5	.364	.403
	Aug. 14	.381	.420
	Aug. 24	.380	.420
	Aug. 31	.364	.503
Means		.328	.410

Climatological Data

Climatic factors have considerable effect on the consumptive use of water by crops. The 1954 growing season in Oklahoma was unusually hot and dry. Considering the variation in consumptive use between years due to variation in climatic factors, the consumptive use for the 1954 growing season would be near the maximum. Climatological data for the 1954 growing season are presented in the following tables in the appendix:

Table 23. Precipitation data for Ft. Reno, Oklahoma 1954.

Table 24. Monthly climatological precipitation data for Ft. Reno, Oklahoma.

Table 25. Average monthly relative humidity at 12:30 P.M., May-September, 1954, Oklahoma City Airport, Oklahoma.

Table 26. Daily evaporation and wind velocity for Lake Overholser, Oklahoma, May-September, 1954.

Table 27. Maximum and minimum daily temperatures for El Reno, Oklahoma, May-September, 1954.

Table 28. Total daily solar radiation in gram-calories per square centimeter, May-September, 1954, Stillwater, Oklahoma.

VI. SUMMARY AND CONCLUSIONS

A summary of transpiration and consumptive use data for optimum yields of corn, grain sorghum, and forage sorghum, as determimed by the soil moisture sampling method on replicated field plots of Canadian fine sandy loam soil, Fort Reno, Oklahoma, 1954, and subsidiary data on the effect of nitrogen fertilizer, soil moisture extraction patterns, and estimates of soil moisture evaporation for the three crops, are presented as follows:

1. The peak daily transpiration rate for corn, which occured July 12-20, was .345 inches. The average daily rate for the irrigation season was .280 inches. The peak monthly rate, which occured in July, was 9.22 inches. The seasonal transpiration was 22.29 inches. The seasonal consumptive use was 26.70 inches, which compares with 23.0 inches calculated empirically by Garton and Criddle for Fort Reno. The net irrigation requirement was 16 inches, which compares with 9.2 inches calculated empirically.
2. Consumptive uses which created a moisture stress in corn from one day to a week greatly reduced the yield. For optimum yields, the soil moisture level should be maintained well above the wilting point throughout the growing season.
3. The application of 90 pounds per acre of nitrogen did not significantly increase the yield of corn over the application of 50 pounds per acre.
4. The peak daily transpiration for grain sorghum, which occured during the heading stage, August 20 - September 1, was .290 inches.

The average daily rate for the irrigation season was .226 inches. The peak monthly rate, which occured during August was 8.60 inches. The seasonal transpiration was 18.25 inches. The seasonal consumptive use was 21.91 inches, which compares with 23.0 inches calculated empirically by Garton and Criddle for Fort Reno. The net irrigation requirement was 15.0 inches, which compares with 9.2 inches calculated empirically.

5. Short moisture stresses in the grain sorghum did not significantly decrease the yields.

6. The application of 50 pounds per acre of nitrogen on grain sorghum did not significantly increase the yield over the application of 25 pounds per acre.

7. The peak daily transpiration rate for forage sorghum, which occured July 29 - August 5, was .381 inches. The average daily rate for the irrigation season was .330 inches. The peak monthly rate, which occured in August, was 11.61 inches. The total seasonal transpiration was 21.74 inches; consumptive use, 23.68 inches. The net irrigation requirement was 21 inches.

8. Moisture stresses in the forage sorghum plants from one day to a week significantly decreased the yield. For optimum yields, the soil moisture level should be maintained well above the wilting point throughout the growing season.

9. Fifty pounds of nitrogen per acre significantly increased the yield of forage sorghum 2.8 tons per acre, from 21.8 to 24.6 tons, over 25 pounds per acre.

10. The percent of total soil moisture extracted from each foot of root zone depth for each crop is presented as follows:

Corn extracted 45.5 percent from first foot, 34.2 percent from second foot, and 20.3 percent from third foot. Grain sorghum extracted 59.0 percent from first foot, 32.0 percent from second foot, and 9.0 percent from third foot. Forage sorghum extracted 56.9 percent from first foot, 30.6 percent from second foot, and 12.5 percent from third foot.

11. The estimate of daily soil moisture evaporation following application from corn was .247 inches; from grain sorghum, .103 inches; and forage sorghum, .082 inches.

12. Continuation of this research project is recommended to evaluate transpiration and consumptive use with variations in climatic conditions and to more closely define the consumptive use for optimum yield of corn and forage sorghum. The following changes in procedure are recommended for continued study:

    a. Use calibrated nylon or similar blocks for soil moisture sampling.

    b. Obtain soil moisture samples on all replicates at representative sites.

    c. Change the statistical design from randomized block to completely randomized if same plot area is used.

    d. Use a higher soil moisture treatment to obtain maximum yield for corn and forage sorghum.

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APPENDIX

Table 19. Irrigation applications, transpiration, and consumptive use of water by corn.

Date	Number of Irri-gation	Daily Transpiration Between Irrigations (Average for period) Inches 0-1'	1-2'	2-3'	0-3'	Length Usage Period Days	Trans-piration Inches	Consump-tive Use Inches
Treatment - T_4								
May 15					.108	33	3.57*	8.63**
June 17					.238	14	3.34	
July 1	1	.138	.133	-	.260	11	2.86	4.0
July 12	2	.145	.108	.105	.260	8	2.76	4.0
July 20	3	.151	.104	.089	.345	9	3.10	4.0
July 29	4	.141	.097	.061	.247	27	6.66	5.75
								0.22***
Totals							22.29	26.70
Treatment - T_3								
May 15					.108	33	3.57*	8.63**
June 17					.238	14	3.34	
July 1	1	.138	.122	-	.260	13	3.38	4.0
July 14	2	.153	.118	.061	.322	12	3.97	4.0
July 26	3	.112	.030	.031	.173	30	5.20	5.75
								1.00***
Totals							19.46	23.38
Treatment - T_2								
May 15					.108	33	3.57	8.63**
June 17					.238	14	3.34	
July 1	1	.084	.058	.052	.194	19	3.69	4.0
July 20	2	.057	.064	.038	.159	36	5.72	5.75
								1.12***
Totals							16.32	19.50

* Transpiration between May 15 and July 1 assumed to 80% of rainfall April 1 - June 30. Transpiration May 15 to June 17 = 80(8.63) - 3.34 = 3.57 inches.

** Total rainfall April 1 to June 30.

*** Differential soil moisture between beginning of irrigation season and harvest (July 1 - August 25).

Table 20. Irrigation applications, transpiration, and consumptive use of water by grain sorghum.

Date	Number of Irri-gation	Daily Transpiration Between Irrigations (Average for period) Inches				Length Usage Period Days	Trans-piration Inches	Consump-tive Use Inches
		0-1'	1-2'	2-3'	0-3'			
Treatment - T_4								
June 16		.044	.040	-	.084	22	1.85	
July 8	1	.109	.121	-	.230	8	1.74	3.0
July 16	2	.100	.108	-	.208	14	2.92	3.0
July 30	3	.256	.130	-	.386	8	2.70	3.84
Aug. 7	4	.182	.124	.044	.350	11	3.84	3.91
Aug. 18	5	.190	.082	.034	.306	9	2.61	3.0
Aug. 27	6	.105	.069	.059	.230	23	5.29	3.0
							0.85*	4.57**
Totals							21.80	24.32
Treatment - T_3								
June 16		.044	.040	-	.084	22	1.85	
July 8	1	.087	.076	-	.163	16	2.60	3.0
July 24	2	.204	.045	-	.249	14	3.50	3.84
Aug. 7	3	.159	.087	.036	.282	13	3.66	3.91
Aug. 20	4	.158	.087	.043	.290	12	3.48	3.0
Sept. 1	5	.082	.063	.032	.181	18	3.26	3.0
							1.91*	5.16
Totals							20.26	21.91
Treatment - T_2								
June 16		.048	.044	-	.092	30	2.76	
July 16	1	.091	.078	.029	.188	22	4.14	3.84
Aug. 7	2	.058	.081	.043	.182	20	3.64	3.91
Aug. 27	3	.082	.052	.043	.177	23	4.06	3.0
							0.44*	5.65**
Totals							15.04	16.40

* Transpiration from maturity to harvest.

** Differential soil moisture between beginning of irrigation season and harvest.

Table 21. Irrigation applications, transpiration, and consumptive use of water by forage sorghum.

Date	Number of Irri- gation	Daily Transpiration Between Irrigations (Average for period) Inches				Length Usage Period Days	Trans- piration Inches	Consump- tive Use Inches
		0-1'	1-2'	2-3'	0-3'			
Treatment - T_4								
June 16					.044	24	1.06	
July 10	1	.076	.097	-	.173	7	1.21	3.0
July 17	2	.123	.098	.037	.258	12	3.10	3.0
July 29	3	.302	.077	-	.379	7	2.65	3.84
Aug. 5	4	.245	.101	.018	.364	9	3.25	3.91
Aug. 14	5	.206	.107	.078	.381	10	3.81	3.0
Aug. 24	6	.188	.124	.068	.380	7	2.66	3.0
Aug. 31	7	.175	.101	.087	.364	11	4.00	3.0
								0.93*
Totals							21.74	23.68
Treatment - T_3								
June 16					.044	24	1.06	
July 10	1	.121	.060	-	.181	13	2.36	3.0
July 23	2	.188	.089	.066	.343	12	4.11	3.84
Aug. 5	3	.202	.122	-	.324	11	3.56	3.91
Aug. 16	4	.112	.089	.036	.237	14	3.52	3.0
Aug. 30	5	.101	.057	.070	.228	13	2.96	3.0
								2.54*
Totals							17.37	19.29
Treatment - T_2								
June 16					.090	31	2.78	
July 17	1	.082	.030	.035	.168	19	3.19	3.84
Aug. 5	2	.136	.079	-	.216	19	4.10	3.91
Aug. 24	3	.106	.037	-	.143	18	2.57	3.0
								5.30
Totals							12.64	16.05

* Differential soil moisture between beginning of irrigation season and harvest (June 16 - Sept. 11).

Table 22. Soil characteristics of plot area, Canadian fine sandy loam.

	Field Capacity Percent	Wilting Point Percent
Calculated*	17.12	6.86
Estimated from sampling	18 - 19	7.5 - 8.5

Apparent Specific Gravity**			
Soil Depth Feet	Corn	Grain Sorghum	Forage Sorghum
0-1	1.46	1.48	1.41
1-2	1.37	1.34	1.40
2-3	1.41	1.36	1.35

Real Specific Gravity

2.63

* Field capacity was calculated by use of ceramic plates for 1/3 atmosphere tension. Wilting point was calculated by use of pressure membrane apparatus for 15 atmospheres tension. Calculations were made by Walter Knisel, Graduate Fellow, Oklahoma A & M College.

** Apparent specific gravity values are average values for three undisturbed core samples taken by the Pomona soil sampler.

Table 23. Precipitation data for Fort Reno, Oklahoma, 1954.

Month	Day	Rainfall Inches
April*	12	.40
	13	.59
	15	.13
	28	.39
	30	.87
Total		2.38
May*	2	1.23
	9	.18
	10	.23
	11	.25
	12	.93
	16	.10
	17	.32
	18	.26
	23	.01
	24	.93
	25	.08
	26	.18
	30	.35
	31	.45
Total		5.50
June*	15	.75
July		None
August	2	.84
	7	.91
	29	.10
	30	.21
Total (August)		2.06
September		None

* Data for April, May, and June were taken from Climatological data reported for El Reno, Oklahoma.

Table 24. Monthly climatological precipitation data for Fort Reno, Oklahoma.

Month	1954 Rainfall Inches	Normal Rainfall Inches	Deviation from Normal Inches
April	2.38	3.21	-0.83
May	5.50	4.54	+0.96
June	0.75	3.82	-3.07
July	None	2.43	-2.43
August	2.06	2.81	-0.75
September	None	3.05	-3.05
Totals	10.69	19.86	-9.17

Table 25. Average monthly relative humidity at 12:30 P. M., May-September, 1954, Oklahoma City Airport, Oklahoma City, Oklahoma.

Month	Relative Humidity Percent
May	63
June	46
July	35
August	38
September	32

Table 26. Daily evaporation and wind velocity for Lake Overholser, Oklahoma, May - September, 1954.

Day of Month	May		June		July		August		September	
	Evap.	Wind	Evap.	Wind	Evap.	Wind	Evap.	Wind	Evap.	Wind
1	.12	84	.20	97	.19	-	.23	62	.26	24
2	.23	144	.28	66	.32	43	.38	99	.32	36
3	.09	214	.41	121	.44	63	.24	48	.39	47
4	.30	68	.25	67	.39	-	.29	78	.46	70
5	.23	43	.28	53	.32	102	.67	119	.42	69
6	.16	53	.41	124	.34	19	.47	93	.34	51
7	.21	105	-	129	.41	43	.36	60	.33	59
8	.13	35	.29	40	.41	31	.15	66	.27	22
9	.19	56	.30	77	.32	29	.09	36	.30	34
10	.05	64	.44	112	.37	35	.26	17	.21	30
11	.07	42	.37	74	.51	74	.22	39	.26	22
12	.36	53	.34	70	.49	61	.76	127	.29	18
13	-	30	.35	69	.41	21	.37	62	.31	41
14	.18	20	.33	59	.46	40	.44	67	.42	71
15	.20	24	.38	82	.54	81	.45	106	.25	14
16	.23	53	.07	30	.07	50	.33	95	.36	30
17	.10	34	.34	74	.41	37	.49	103	.37	38
18	.08	36	.36	84	.51	66	.35	88	.25	34
19	-	21	.32	52	.51	81	.68	125	.36	100
20	.24	40	.41	51	.48	78	.37	95	.48	145
21	.14	39	.36	54	.37	81	.35	61	.57	141
22	.24	83	.34	62	.54	85	.31	59	.22	41
23	.28	89	.31	23	.47	74	.35	67	.35	23
24	.24	62	.31	17	.43	45	.28	51	.30	52
25	.11	17	.42	62	.31	24	.27	54	.28	44
26	.21	30	.39	56	.36	41	.45	62	.23	28
27	.25	57	.37	54	.37	47	.42	81	.15	10
28	.25	64	.37	50	.32	33	.46	30	.35	68
29	.28	56	.40	83	.28	23	.37	38	.31	116
30	.22	51	.30	-	.35	40	.22	22	.22	89
31	.28	110			.32	57	.15	48		
Totals	6.06		10.03		12.02		11.18		9.63	
Means	.20	61	.34	69	.39	50	.36	74	.32	52

Table 27. Maximum and minimum daily temperatures for El Reno, Oklahoma, May - September, 1954.

Day of Month	May		June		July		August		September	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	64	47	82	51	97	71	97	72	99	67
2	63	39	79	61	99	72	98	65	101	70
3	54	31	76	50	99	72	102	71	103	72
4	64	34	79	45	100	72	101	75	97	70
5	73	46	86	60	100	69	102	79	95	66
6	80	52	89	68	102	73	105	78	99	71
7	70	49	87	66	103	73	102	93	96	74
8	70	48	90	65	103	76	76	69	97	66
9	66	52	90	65	104	72	95	59	91	74
10	55	46	90	71	102	75	99	64	85	58
11	54	50	93	70	106	72	102	74	90	51
12	69	50	94	73	108	74	101	77	91	59
13	74	47	92	67	108	77	102	69	97	58
14	76	51	93	71	109	77	102	78	97	69
15	79	55	87	61	99	78	103	79	98	66
16	84	62	90	65	104	71	102	78	97	67
17	71	60	93	73	106	73	101	76	94	69
18	77	55	94	72	106	76	100	76	96	68
19	74	52	74	71	105	78	99	78	100	75
20	71	55	93	73	104	74	101	73	100	77
21	81	53	94	71	102	78	96	73	90	59
22	83	62	99	71	104	79	97	75	85	48
23	80	64	99	69	101	76	91	71	88	54
24	75	60	98	71	104	74	95	69	91	53
25	77	61	97	72	109	72	98	71	94	58
26	80	59	96	71	98	80	99	76	90	66
27	84	60	94	72	99	74	101	76	96	69
28	81	65	95	69	99	73	102	75	95	68
29	81	53	96	67	101	72	103	71	95	65
30	86	69	96	69	95	68	105	69	74	63
31	83	61			93	74	95	69		
Means	73.5	53.2	91.2	66.6	102.2	74.0	99.1	72.8	94.1	65.0

Table 28. Total daily solar radiation* in gram-calories per square centimeter, May - September, 1945, Stillwater, Oklahoma.

Day of Month	Month				
	May	June	July	August	September
1	165.3	723.0	688.8	570.9	576.0
2	500.7	521.4	683.1	660.9	573.0
3	787.5	769.8	629.8	858.2	558.4
4	722.7	712.0	727.2	642.3	564 7
5	739.3	687.9	724.5	624.6	546.7
6	582.9	410.7	688.8	469.5	554.7
7	669.9	587.1	551.4	577.8	258.1
8	273.7	681.3	687.9	272.7	524.4
9	220.0	724.2	578.7	539.9	409.8
10	188.5	729.6	711.6	630.9	578.7
11	152.1	682.8	709.2	629.5	543.3
12	555.3	337.4	694.2	658.5	550.8
13	666.9	670.2	677.7	613.8	521.5
14	682.2	576.6	665.4	529.2	212.7
15	648.3	524.4	406.8	522.0	474.6
16	358.6	709.5	707.1	578.1	497.1
17	106.2	721.5	701.1	570.0	499.2
18	701.6	690.0	671.4	606.6	505.9
19	442.8	667.5	671.7	348.9	460.1
20	383.7	701.7	676.8	603.0	456.3
21	621.6	715.5	447.9	490.8	543.9
22	621.6	586.8	631.2	563.7	525.8
23	516.3	683.1	697.5	403.4	514.2
24	607.1	720.9	614.4	501.3	492.9
25	-	721.4	617.4	573.4	300.6
26	544.2	654.0	406.8	490.4	311.7
27	717.0	707.1	693.9	580.5	212.7
28	591 9	721.8	523.5	529.6	448.2
29	736.5	661.1	692.7	539.1	301.7
30	742.4	430.5	643.9	492.6	163.9
31	645.4		480.5	514.0	
Totals	15,802.2	19,432.7	19,664.9	17,296.1	13,681.6
Means	526.7	647.8	634.4	557.9	456.1

* Solar radiation values were determined with an Eppley Type Phyrhelio-meter, horizontal surface element, which measures total sky radiation (direct sky radiation plus diffuse sky radiation).

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